

Poor Sleep and Lower Working Memory in Grade 1 Children: Cross-Sectional, Population-Based Study



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ABSTRACT

OBJECTIVE: Poor sleep and working memory difficulties are both associated with learning difficulties, but it is not known whether they are linked with each other in childhood. We aimed to determine, in a population-based sample of grade 1 children, whether poor sleep is associated with reduced working memory capacity.

METHODS: Cross-sectional population-based study. All grade 1 children in 44 elementary schools in metropolitan Melbourne, Australia; 1749 children were included (participation rate 65%, mean age 6.9 years). Parents completed a written questionnaire at home, after which researchers administered one-on-one child computerized assessments at school. Predictor measures were parent-reported 1) perceptions of poor sleep, 2) regularity of bedtime, 3) sleep duration, and 4) sleep onset latency. Outcome measures were backward digit recall (verbal working memory) and Mister X (visuospatial working memory) subtests of the

Automated Working Memory Assessment (AWMA). Associations were examined using linear regression, adjusted for duration of schooling, gender, age, and social status.

RESULTS: Increasing poor sleep ($P = .03$), less regularity of bedtime ($P < .001$), and shorter sleep duration ($P = .03$) were all associated with poorer verbal working memory, with effect sizes ranging from 0.3 to 1.2. Poor sleep was not associated with visuospatial working memory.

CONCLUSIONS: At a population level, poor sleep in early school-age children is associated with poorer verbal working memory, an important predictor of academic difficulties.

KEYWORDS: child; cross-sectional studies; epidemiology; learning difficulties; memory; short-term; sleep

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WHAT'S NEW

Although sleep problems are consistently associated with poorer working memory in adults, findings in school-age children remain limited. We demonstrate, at a population level, that sleep problems and irregular bedtimes are associated with poorer verbal, but not visuospatial, working memory performance.

BUILDING SOLID ACADEMIC foundations during the early years of school is strongly associated with long-term academic outcomes¹ as well as social and employment outcomes in later life.² Working memory—a child's ability to remember and manipulate new information—is crucial in enabling a child to learn.^{3,4} A good night's sleep is also considered an essential prerequisite for successful learning. Children who experience poor sleep, typically defined as disrupted or inadequate sleep, are at greater risk of poor academic attainment and grade repetition.^{5,6} Although studies have reported that poor sleep is related to

poorer working memory⁷ and other executive functions,^{8,9} there are no population-level data about what specific aspects of sleep are associated with poorer working memory during the early years of school. In particular, if aspects of poor sleep were causally related to low working memory, affected children's ability to learn in the early years of school may be improved via sleep interventions, already known from translational trials to be practicable and effective in population settings.^{10,11}

Working memory can be differentiated into verbal and visuospatial components. Verbal working memory involves storing and manipulating auditory/verbal stimuli such as sounds, phonemes, and words for a short period. This is considered important for language and literacy development and is involved in remembering, comprehending, and following instructions.¹² Visual-spatial working memory, which involves storing and manipulating visually presented information, is needed for numeracy development and to remember sequences of patterns, events, or images.¹² Children with weak working memory

may become overloaded in the classroom and forget crucial task information. This is because working memory is used to construct mental models for problems (eg, word and sentence construction) and to coordinate multiple tasks,¹³ including monitoring and manipulation of mental calculations and task sequences.^{14,15}

In this study, we focused on the possible role of poor sleep in influencing a child's working memory. Poor sleep is common, affecting about 40% of children during the preschool and early years of school.^{16,17} It is associated with increased behavior problems, poorer concentration, and poor academic attainment in school.^{7,18} A review by Kopasz et al⁸ reported that inadequate or disrupted sleep is associated with poorer prefrontal cortex function, which encompasses working memory. More recently, it has been reported that preschool children who slept longer at night performed better on higher-order cognition.⁹ Research also suggests differences in child learning are related to sleep duration on both school and non-school nights,¹⁹ bedtime regularity,²⁰ and sleep latency (the time it takes a child to fall asleep while in bed).²¹

Poor sleep is consistently associated with poorer working memory performance in adolescent and adult populations,²² but the relationship between multiple aspects of sleep and working memory have not been examined at a population level in early childhood. This is an important research gap, as the characteristics of poor sleep, the development of working memory, and the consequences of poor working memory are different in young children compared with adults. Adult sleep problems typically have a medical etiology, such as obstructive sleep apnea, whereas sleep problems in children are predominantly behavioral in nature, such as bedtime resistance and sleep phase disorders.²³ Whereas working memory is thought to be stable in adults, it is still developing in children.²⁴ A study of 60 children aged 6 to 13 years by Steenari et al⁷ reported that actigraphy measurements of reduced sleep quality was associated with poorer working memory scores on the n-back test. It is important to understand whether this relationship persists at the population level in order to inform future working memory intervention trials using evidence-based population-level sleep interventions.^{10,11} Sleep interventions may offer a quicker, more developmentally appropriate, and less disruptive mechanism for maximizing working memory performance compared with intensive and expensive working memory training programs.

We aimed to determine the association between a range of parent-reported child sleep parameters and working memory in a population-level cohort of early elementary school children. We hypothesized that parent-reported sleep problems, irregular sleep times, shorter sleep duration, and increased sleep latency would all be associated with lower verbal and visual working memory.

METHOD

This cross-sectional study used baseline population-level screening data from the large Memory Maestros randomized control trial, described in detail in its published

protocol.²⁵ Memory Maestros was approved by the human research ethics committee at the Royal Childrens Hospital in Melbourne, Australia (HREC 30104), the Victorian Department of Education and Early Childhood Development, and the Victorian Catholic Education Office, and parents provided written informed consent for each child to participate.

DESIGN AND SAMPLE

Elementary schools were randomly selected from each of Melbourne's 4 metropolitan school regions (northern, southern, western, and eastern) and were proportionately drawn from all 3 school sectors (government, independent, and Catholic). The regions and sectors represent a broad range of socioeconomic and cultural backgrounds.²⁶ Recruitment of grade 1 children in the 44 schools occurred in 2012 over the 4 terms of the school year. Grade 1 refers to the second formal school year in Victoria, Australia, when almost all children are aged between 6 and 7 years.

PROCEDURES

Recruitment packs were sent to families of all grade 1 students via the classroom teacher in all participating schools. The recruitment pack included the parent information statement, consent form, and parent baseline questionnaire. Because the questionnaires were completed before the working memory assessments, parents were unaware of the child's working memory abilities. Children were excluded if they had conditions that prevented them participating in the computerized working memory screening tasks (eg, blind, deaf, selective mutism) or if their parents had insufficient English-language skills to complete the screening survey.

Once all informed consent forms had been received for a given school, trained research assistants administered the working memory assessments to each child individually. Assessments were conducted within 1 week of informed consent and the baseline questionnaire being received, and all assessments occurred during school hours.

MEASURES

Parents reported on several child sleep variables.⁴ Child sleep problems were assessed by parent response to the question, "Is your child's sleep or sleep habits a problem for you?" The 4 possible responses were trichotomized into no, small, and moderate/large sleep problem, in line with previous research examining the relationship between sleep problems and objectively measured child learning.⁴ Child sleep patterns were assessed by parent response to the question, "Does your child go to bed at regular times?" The 5 possible responses were trichotomized into always/usually, sometimes, and never/rarely categories of sleep pattern regularity, in line with previous research.⁴ Child sleep time, duration, and latency were derived from parent answers regarding the time the child usually 1) went to bed, 2) fell asleep and 3) woke up, with separate responses elicited for school days and non-school days. Specifically,

sleep latency was calculated as the period between when the child usually went to bed and the time they usually fell asleep. Sleep duration was calculated as the interval between when the child usually fell asleep and when they usually woke. Parent reports of sleep problems and duration in young children have strong correlations with objective measures of sleep such as actigraphy²⁷ and are also widely accepted as being feasible and acceptable for population-based studies.²⁸

Each child's working memory was assessed on 2 subtests from the computerized Automated Working Memory Assessment (AWMA).²⁹ The backward digit recall subtest measured verbal working memory and the Mister X subtest measured visuospatial working memory. Two working memory subtests have been successfully used previously to identify children with working memory difficulties and are sufficiently sensitive to detect changes in working memory after intervention.^{30,31}

STATISTICAL ANALYSIS

All statistical analyses were conducted by Stata, version 12.0 (StataCorp, College Station, Tex).

Child and caregiver characteristics, sleep variables, and working memory scores were described using standard statistical summary measures. The association between each of our sleep variables with working memory scores (verbal and visuospatial) was determined using linear regression to determine mean differences between groups. For all analyses, robust regression analyses were conducted to correct for the clustered recruitment of children by school, and we conducted unadjusted and adjusted analyses accounting for potential confounders. Confounders, chosen a priori on the basis of previous literature for adjusted analyses, were duration of schooling, child gender,³² age,⁵ and family socioeconomic status,³³ all ascertained through child and family demographics in the parent questionnaire.

RESULTS

SCHOOL AND SAMPLE CHARACTERISTICS

The numbers of schools participating from each sector (32 government, 8 Catholic, and 4 independent schools) approximated the expected proportions in metropolitan Melbourne, although participation rates within schools were slightly higher for Catholic schools (75%, vs 65% for the other 2 sectors). The participant flow is reported in the [Figure](#). Overall, of the 2747 parents approached, 1790 parents (65.2%) consented to participation, of whom 1786 (99.9%) completed the questionnaire. A total of 1752 children (97.9%) completed the working memory assessments, with the remaining 38 either absent on the screening days or having classroom commitments that precluded leaving the classroom. Complete questionnaire and working memory data were available for 1740 children (96.1%). [Table 1](#) shows that boys and girls were similarly represented in the sample. About two-thirds of parents had completed a tertiary education, which is higher than the 43% expected from Australian census data.²⁷ Common

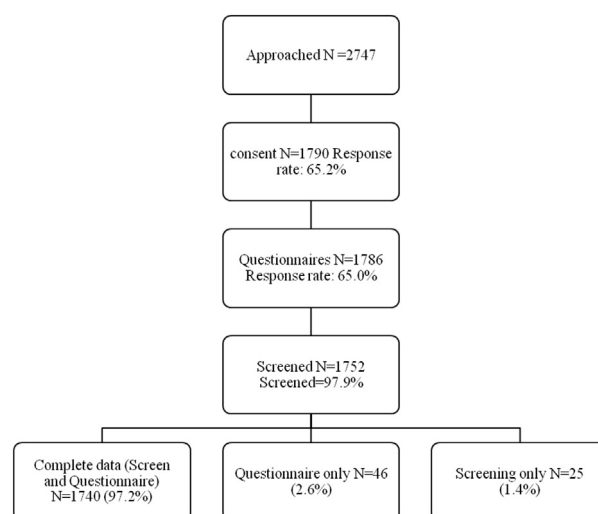


Figure. Memory Maestros participation response rates.

developmental and behavioral problems were not over- or underrepresented in this cohort.

SLEEP AND WORKING MEMORY CHARACTERISTICS

Overall, 7.9% of parents reported their child had a moderate or large sleep problem, and 2.1% reported their child did not have a regular bedtime. On average, children sleep for 10.6 hours (SD = 38.2 minutes) on school nights with a mean sleep latency of 26.7 minutes (SD = 20.7 minutes). On non-school nights, children sleep for an average of 10.4 hours (SD = 43.7 minutes) with a reported mean latency of 23.4 minutes (SD = 19.4 minutes). These sleep durations are similar to reported Australian norms.³⁰

The unadjusted mean working memory raw scores were 9.3 (SD = 0.9) for verbal working memory and 8.4 (SD = 0.9) for visuospatial working memory. These mean scores are on the 63rd and 75th percentiles for each subtest on the basis of normed scores, respectively. This suggests our population performed better overall compared to the UK population that the measure was standardized on.

ASSOCIATIONS BETWEEN POOR SLEEP AND WORKING MEMORY SCORES

As shown in [Table 2](#), parent reports of increasing sleep problems were associated with poorer verbal working memory scores. Compared with children with no sleep problems, children with mild sleep problems had lower verbal working memory mean scores (mean difference −0.3; 95% confidence interval [CI] −0.7 to 0.1, effect size = 0.3), while those with moderate/severe sleep problems had the lowest mean scores (mean difference −0.5; 95% CI −1.1 to 0.0, effect size = 0.6). There was little difference between groups for visuospatial working memory.

Irregular bedtime was also associated with lower working memory scores. For every hour's increase in sleep duration, children's verbal working memory scores increased by 0.3 (95% CI 0.0 to 0.5, effect size = 0.3). However, there was little evidence that school night sleep duration

Table 1. Sample Demographics and Child Sleep Descriptive Statistics*

Characteristic	Value
<i>Child</i>	
Age, y, mean (SD)	6.9 (0.4)
Male gender	910 (50.2)
Extra assistance for learning at school	
Extra learning help	230 (12.7)
Special education group/class	85 (4.7)
Integration aide	51 (2.8)
Speech therapy	126 (7.0)
Other	100 (5.5)
Current diagnosed condition	
Inattention problem	111 (6.2)
Anxiety	91 (5.1)
Behavioral/conduct problem	62 (3.5)
Developmental delay	51 (2.9)
Autism	32 (1.8)
Intellectual disability	15 (0.8)
<i>Primary caregiver</i>	
Biological parent	1755 (96.9)
Male gender	223 (12.3)
Married/de facto	1573 (86.9)
Highest level of education	
High school	356 (19.6)
Tertiary education†	1209 (66.8)
<i>Household</i>	
Other non-English languages spoken	283 (15.6)
Health care card (pensionlike status)‡	295 (16.3)
<i>Child sleep parameters</i>	
Sleep problems	
No problem	1296 (71.6)
Small problem	329 (18.2)
Large/moderate problem	143 (7.9)
Bed regularity	
Always/usually regular	1667 (92.1)
Sometimes regular	78 (4.3)
Rarely/Never regular	38 (2.1)
<i>Summary parameters, mean (SD)</i>	
On school days	
Sleep duration, h	10.6 (38.2 min)
Sleep latency, min	26.7 (20.7 min)
Bed time	8:03 PM (40.0 min)
Sleep time	8:28 PM (41.4 min)
Wake time	7:05 AM (31.4 min)
On non-school days	
Sleep duration, h	10.4 (43.7 min)
Sleep latency, min	23.4 (19.4 min)
Bed time	8:40 PM (53.6 min)
Sleep time	9:01 PM (52.4 min)
Wake time	7:30 AM (53.1 min)

*All values are n (%) unless otherwise noted. For missing data rates, incompleteness varied between 1.4% (for gender) to 12.7% (for completed tertiary education).

†Tertiary education includes completed undergraduate and postgraduate studies.

‡In Australia, families with low incomes (\$868 combined weekly income for a couple with children) are eligible to receive a health care card. This gives them access to government cost-supplemented prescription medications, health care, and concessions for house amenities, transport, and education costs.

was associated with visuospatial working memory scores or that sleep duration on non-school nights was associated with either working memory score.

Children who had irregular bedtime had poorer verbal working memory scores (mean difference -1.2 ; 95% CI

-2.2 to -0.1 , effect size = 1.2). Bedtime regularity was not associated with visuospatial working memory scores. Sleep latency was not associated with either working memory score.

DISCUSSION

In this study, we demonstrate for the first time at a population level an association between increasing parent reported sleep difficulties and lower verbal working memory in primary school-age children. Specifically, parent report of increasing sleep problem severity, increased bedtime irregularity, and shorter sleep duration were all associated with lower verbal, but not visuospatial, working memory scores.

Our population-level findings are consistent with previous research, which have been limited by small samples and/or wide age groups.⁷⁻⁹ Our findings are consistent with a review conducted by Kopasz et al,⁸ who reported that sleep disruption in children compromises prefrontal cortex functioning, of which working memory is a function. Bernier et al⁹ also demonstrated that sleep problems in infants were related to poorer executive functioning during preschool. One study has specifically examined working memory in school-age children. Steenari et al⁷ reported in a sample of 60 students aged 6 to 13 years that children with sleep problems, as defined by actigraphy measurements, had greater difficulty in verbal working memory tasks but no other domains. However, we did not find sleep latency to be associated with poorer working memory, which may be a result of using parent recall compared to actigraphy measurements. Overall, our findings demonstrate at a population level that there is an association between sleep problems with verbal, but not visuospatial, working memory.

It remains unclear as to why we did not find an association between poor sleep and visuospatial working memory. Although both measures we administered are established validated instruments, they are multifactorial and suffer from task impurity.³⁴ In other words, whereas successful performance on backward digit recall and Mister X tasks are dependent on working memory, they are also dependent on other cognitive skills, including selective attention, impulse control, processing speed, and mental flexibility. The visuospatial task may have been more motivating to the children, and therefore they were less affected by tiredness, compared with the verbal task. Further, the association between sleep problems and working memory may be an indirect relationship. It is possible that the children with sleep problems may more frequently have other underlying behavioral issues, such as attention-deficit/hyperactivity disorder, that may be associated with lower working memory capacities. Longitudinal follow-up of this cohort is likely to provide more insight into the relationship between sleep and working memory.

This study has several strengths. First, to our knowledge, this is the first population-based study of grade 1 children to explore the associations between sleep problems and working memory. Although our sample was slightly

Table 2. Associations Between Sleep Parameters and Working Memory*

Sleep Parameter	Verbal Working Memory			Visual Working Memory		
	Mean (SD)	Mean Difference (95% CI)	P	Mean (SD)	Mean Difference (95% CI)	P
Sleep problems						
None	9.9 (0.9)	Reference	.04	8.1 (0.7)	Reference	1.0
Mild	9.6 (0.9)	−0.3 (−0.7, 0.1)		7.8 (0.7)	−0.2 (−0.7, 0.2)	
Moderate/large	9.2 (1.0)	−0.5 (−1.1, 0.0)		8.2 (0.7)	0.1 (−0.4, 0.8)	
Bed regularity						
Always/usually	9.9 (0.9)	Reference	<.001	8.0 (0.7)	Reference	.5
Sometimes	8.4 (1.0)	−1.2 (−2.0, −0.5)		7.9 (0.7)	0.1 (−0.7, 0.9)	
Rarely/never	8.4 (1.0)	−1.2 (−2.2, −0.1)		8.4 (0.7)	0.5 (−0.6, 1.7)	
Sleep duration—school night†		0.3 (0.0, 0.5)	.02		0.0 (−0.3, 0.3)	1.0
Sleep duration—non-school night†		0.0 (−0.1, 0.3)	.4		0.2 (−0.1, 0.4)	.2
Sleep latency—school night‡		0.03 (−0.02, 0.08)	.3		0.06 (−0.02, 0.2)	.1
Sleep latency—non-school night‡		0.03 (−0.05, 0.1)	.4		0.08 (−0.01, 0.2)	.1

SD indicates standard deviation; CI, confidence interval.

*Adjusted for duration of schooling, gender, age and social status. P values from combined Wald test across the categories or individual Wald test where continuous variables.

†Mean difference according to 1-hour increase in sleep duration.

‡Mean difference according to 10-minute increase in sleep latency.

more advantaged than expected in Melbourne,²⁷ recruiting children from a large number of schools across the metropolitan region and from the government, Catholic, and independent school sectors enabled us to examine the outcomes of a larger and more diverse group of children compared with previous studies.^{14,20} Second, our findings are internally consistent, as we were able to demonstrate similar effects across several domains of sleep. We did not exclude children with common developmental and behavioral problems, such as autism or attention problems. The rates of these conditions in our cohort are comparable to other population-based cohort studies,⁴ suggesting that our results are generalizable.

This study also had some limitations. First, we used parent report of child sleep problems and sleep characteristics. Parent reports in the child's bed, sleep, and wake time may be prone to recall bias and may not account for day-to-day variation.²⁸ However, these subjective measures are more feasible in population-based research compared to expensive and time-consuming objective measures such as actigraphy and polysomnography.²⁸ The use of parent-reported questionnaire data is advantageous in population-based studies because it reflects the child's habitual sleep behavior on a global basis, and also takes in to account parent perception and influences (ie, culture, expectations) on what constitutes a sleep problem.³² Second, we were restricted to 2 direct measures of working memory. However, previous research^{30,31,35} has used these subtests to identify children with low working memory and has demonstrated associations with these measures and behavior, attention, and school readiness. Future research may want to consider a broader assessment of working memory, as well as parent and teacher report measures. Third, it is possible that children who participated in the study may have differed from those who did not with regard to working memory as a result of selectivity of participation. If the study population tended to be higher functioning with regard to working memory, this may have increased the differences seen, but conversely, it may have led to an

understatement of the effects of sleep as a result of the exclusion of some of the more disadvantaged children. Finally, our findings do not infer causality, and future longitudinal research is needed to confirm these findings. Nonetheless, future working memory intervention studies should consider the influence of poor sleep on response to intervention. Conversely, sleep intervention studies should also consider examining working memory as an outcome measure.

In conclusion, our findings show that parent-reported sleep problems, bedtime irregularity, and decreased sleep duration are associated with lower verbal working memory. However, future studies are required to determine the mechanisms underlying the association between poor child sleep and working memory during the early years of school, and whether addressing sleep problems in young children can improve working memory and overall learning.

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